Nonverbal Collaboration on Perceptual Learning Activities with Chemistry Visualizations

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Abstract. Classroom orchestration tools rely on research showing when individual or collaborative activities are effective. No prior research has investigated effects of collaboration on perceptual learning, which is nonverbal and inductive. An experiment compared individual learning to nonverbal, gesture-based collaboration on a perceptual training. Results show an advantage of gesture-based collaboration on pre-to-posttest gains, especially for low-spatial skills students.

Keywords: Perceptual training · Collaboration · Gestures · Spatial skills

1 Introduction

Classroom orchestration tools may help teachers decide when to transition between individual and collaborative instruction. Designing such tools requires research that determines for which types of activities and for which collaboration is effective. For example, following the call to understand under what circumstances collaboration is beneficial [1], research showed that collaboration has differential effects on conceptual vs. procedural learning [2]. We expand this research by testing whether collaboration enhances students' benefit from activities that focus on perceptual learning. Further, we investigate effects on students with low spatial skills who tend to be underrepresented in science, technology, engineering, and mathematics (STEM) [3].

Visual representations are often used in STEM instruction to illustrate abstract concepts [4]. Students need to be able to fluently perceive information shown in visual representations [4, 5]. For example, when chemistry students see a Lewis structure (Fig. 1A), they need to be able to perceive the molecule's 3D geometry (Fig. 1B). Students acquire such perceptual fluency via nonverbal processes involved in inductive pattern learning [5]. These processes are considered nonverbal because verbalization interferes with perceptual learning [6]. To support perceptual fluency, perceptual trainings present students with short nonverbal tasks that ask students to quickly recognize or classify visual representations [4, 7].

A limitation of prior research on perceptual trainings is that it has exclusively focused on individual learning, possibly because of their focus on nonverbal learning. On the one hand, collaboration involves nonverbal communication via gesturing, which can

M. M. Rodrigo et al. (Eds.): AIED 2022, LNCS 13356, pp. 231–235, 2022.
https://doi.org/10.1007/978-3-031-11647-6_41

support perceptual learning [8]. This may be particularly helpful for students with low spatial skills [9]. On the other hand, collaboration enhances learning from complex tasks but not from simple tasks [10], whereas perceptual trainings typically involve simple, one-step tasks. To address these limitations, we test if nonverbal, gesture-based collaboration enhances perceptual learning, if spatial skills moderate the effect of gesture-based collaboration, and if problem-solving behaviors mediate this effect.

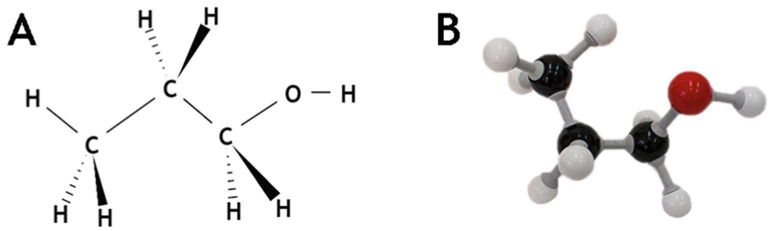

Fig. 1. **A:** 2D wedge-dash Lewis structure; **B:** 3D ball-and-stick model.

2 Methods

The study was conducted in an introductory chemistry course with 45 undergraduate students, taught by one of the authors. The course lasted 15 weeks; the study occurred in weeks 14–15. Three students were excluded from the analysis: two were absent in week 15, and one did not consent to participate in the study, yielding $N = 42$.

Individual students were randomly assigned to conditions. Students in the *collaborative condition* ($n = 22$) worked in dyads on the perceptual learning activities. Dyads were instructed not to talk but to communicate only via gestures, such as pointing and showing shapes. The *individual condition* ($n = 20$) worked alone on the activities.

The perceptual training was provided electronically and was designed based on prior research [4, 5]. To encourage nonverbal, inductive processes, the perceptual training asked students to "solve tasks fast and intuitively without overthinking it." Students received 20 short tasks asked them to select one of four visuals that showed the same molecule as a given visual. The choice options varied a range of visual features that are relevant to chemical isomerism and irrelevant features.

Students took a content knowledge pretest at the start of week 14, an immediate posttest after finishing the perceptual learning activities, and a delayed posttest at the start of week 15. Further, students took a mental rotations test in week 1. We also used logs from the perceptual training to compute Z scores for time on task and error rates. Students in the collaborative condition were assigned the group score.

To analyze the data, we first calculated the intraclass correlation (ICC) to estimate the degree of clustering due to students being nested in dyads. While the ICC for students' immediate posttest scores was nonsignificant ($p = .693$), it was significant for students' delayed posttest scores (ICC $= .506$, $p = .041$). This rejects the assumption of independence of students within dyads. Hence, we used a hierarchical linear model (HLM). Level 1 modeled repeated test-time within students (immediate and delayed posttest).

Level 2 modeled student characteristics (spatial skills, pretest scores). Level 3 modeled student-group variables (condition, interaction between condition and spatial skills). Levels 2 and 3 included random effect for students and student dyads, respectively. To conduct the mediation analysis, we constructed a causal path model.

3 Results

To test if collaboration is effective, we examined the main effect of condition, which was significant, $F(1, 30.7) = 9.89$, $p = .004$. Students in the collaborative condition had higher learning gains than students in the individual condition. To test if spatial skills moderate the effect of collaboration, we examined the interaction between condition and the continuous spatial skills variable, which was significant, $F(1,\ 34.4) = 6.29$, $p = .017$. Students with lower spatial skills benefitted more from collaboration (see Fig. 3A). To test if problem-solving behaviors mediate the effect of collaboration, we first verified whether collaboration affected problem-solving behaviors. The HLM showed a significant effect on error rates, $F(1,\ 33.3) = 5.48$, $p = .025$, but not on time on task ($F < 1$). There was no significant interaction between condition and spatial skills ($F < 1$). Thus, we used only error rates for the mediation analysis. The causal path model fits the data, χ^2 (9, $N = 42$) = 13.0074, $p = .163$) (Fig. 3B). Error rates fully mediate the effect of condition on immediate posttest: collaborating students made fewer errors, which increased performance on the immediate posttest.

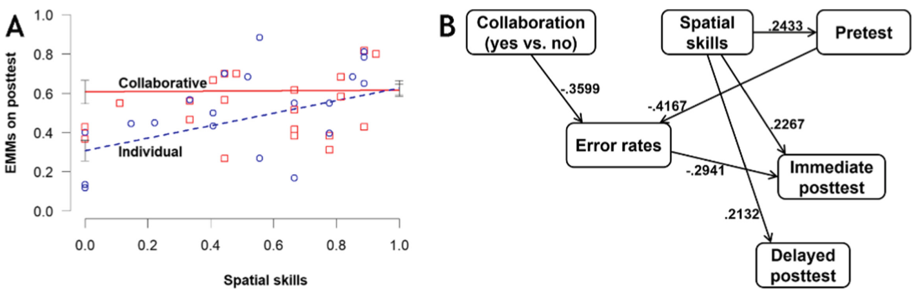

Fig. 3. **A:** Interaction of condition with spatial skills. The y-axis shows estimated marginal means (EMMs, averaged across immediate and delayed posttests). Error bars show standard errors of the means. **B:** Summary of causal path analysis model, unstandardized coefficients.

4 Discussion

This study tested whether nonverbal, gesture-based collaboration enhances perceptual learning. We found a large benefit of gesture-based collaboration, especially for low-spatial skills students, which was fully mediated by a reduction of error rates.

Our results extend prior research in several ways. First, adding to research showing that perceptual learning can occur in social settings [8], we found that gesture-based enhances perceptual learning. Second, in contrast to research suggesting that verbal collaboration interferes with perceptual learning [6] our findings suggest that this assertion does not extend to gesture-based collaboration.

Further, our findings expand prior research by providing pathways for addressing an equity issue for students with low spatial skills. Our study suggests that gesture-based collaboration may help address this issue. Specifically, students with low spatial skills may have difficulties in mentally rotating visual features so that they can translate between the visuals. A partner who is more proficient at this task may help them see mappings between the visuals and thereby help them recognize perceptual patterns.

Limitations of our study include that we did not observe students' nonverbal communication and that it had a relatively small sample size.

To conclude, our study is the first to establish that nonverbal collaboration via gesturing enhances students' benefit from activities focused on perceptual learning with visual representations. These findings can inform the design of classroom orchestration systems that can help instructors decide which activities lend themselves to collaborative work, and which students might benefit from them.

Acknowledgements. This work was supported by a 2019 National Academy of Education (NAEd)/Spencer Postdoctoral Fellowship. We thank Judith Burstyn, Edward Misback, and the Chemistry Department.

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